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MK 13-1 TORPEDO WITH VARIOUS NOSES

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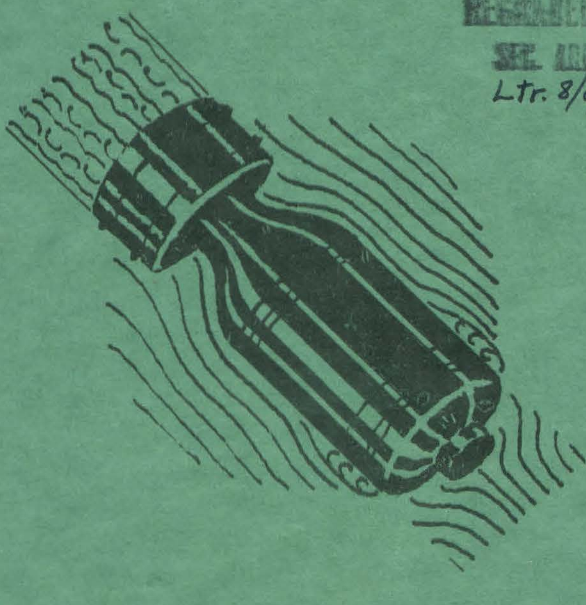

THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

SECTION № 6.1-sr 207-1909
HML № ND-15.4

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TESTS OF THE MK 13-1 TORPEDO WITH VARIOUS NOSES

ROBERT T. KNAPP
OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRAULIC MACHINERY LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr207-1909

HML NO. ND-15.4

Report Prepared by
Harold L. Doolittle
Hydraulic Engineer

February 1, 1945

TESTS OF THE MK 13-1 TORPEDO
WITH
VARIOUS NOSES

GENERAL

This report covers model tests of the MK 13-1 Torpedo without shroud ring tail, conducted at the Hydraulic Machinery Laboratory of the California Institute of Technology. These tests were made at the request of Dr. E. H. Colpitts, Chief of Section 6.1, National Defense Research Committee, in a letter dated October 8, 1943, and were for the purpose of determining the performance of the torpedo with seven different types of nose design.

Report, Section No. 6.1-sr207-936, dated November 9, 1943, covers tests of this torpedo with the standard MK 13-1 torpedo nose. This supplemental report describes the performance of the torpedo fitted with the following noses:

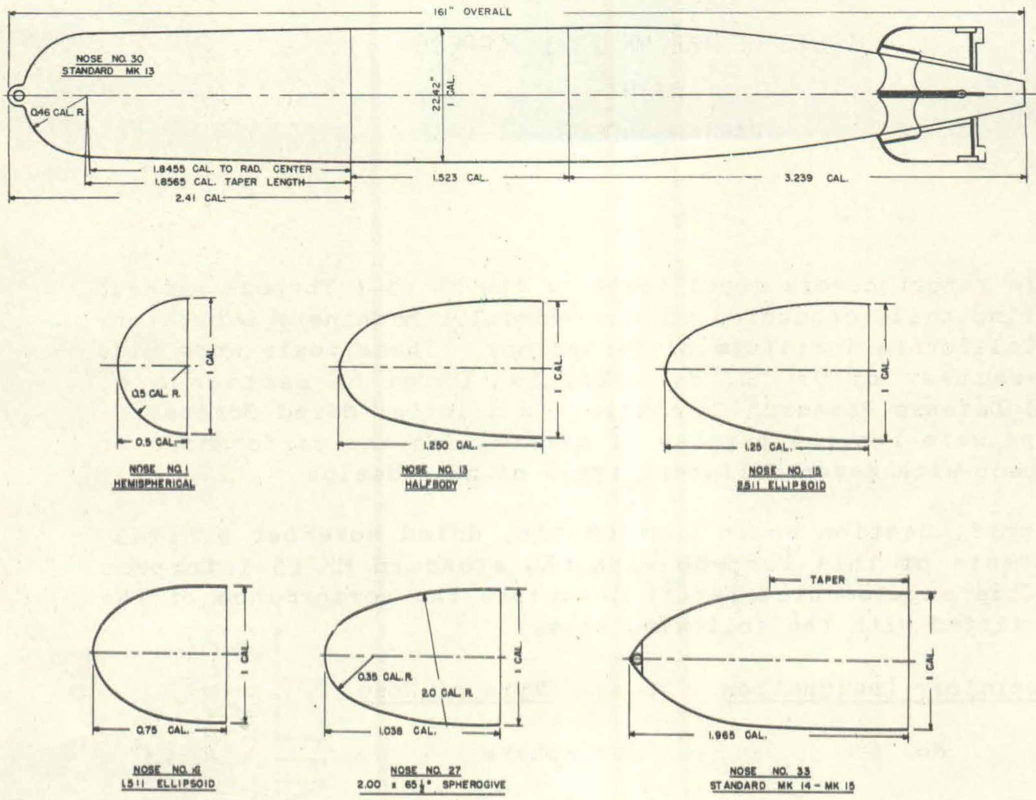
Laboratory Designation	Type of Nose
No. 1	Hemisphere
No. 13	Halfbody
No. 15	2.5 : 1 Ellipsoid
No. 16	1.5 : 1 Ellipsoid
No. 27	2.0 caliber x 65-1/2° spherogive
No. 30A	MK 13 Torpedo (0.46 caliber spherical tip with taper 1.845 calibers long)
No. 33	MK 14 and MK 15 Torpedo

DESCRIPTION OF PROJECTILE

In these tests a constant overall length, corresponding to that of the MK 13 Torpedo, was maintained regardless of the type of nose used. Following are the dimensions of the prototype:

Diameter	22.42 inches
Length overall	161.00 inches
Distance from nose to C.G.	73.82 inches

The model is 2" in diameter, which gives a model scale of 1 : 11.21.

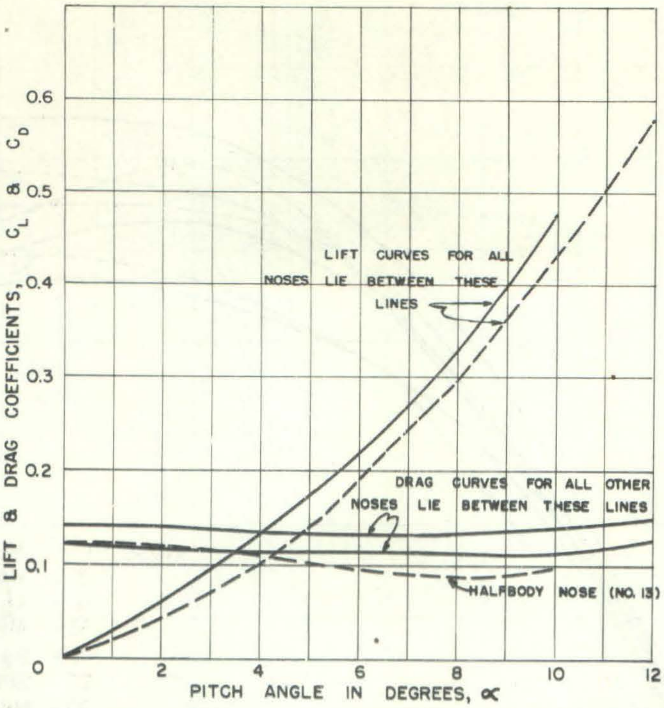


OUTLINE DRAWINGS OF TORPEDO AND NOSE DESIGNS

FIGURE 1

Figure 1 shows an outline drawing of the torpedo fitted with the standard MK 13 nose. This figure also shows the comparative dimensions of the other six nose designs tested.

The so-called "halfbody" nose is a special calculated profile based upon the halfbody resulting from the combination of a source in a rectilinear flow. The nose profile is formed by joining this mathematical curve to the cylinder with a transition curve that gives continuity of the slope and curvature. It will be noted that this profile is similar to a 2.5 : 1 ellipsoid, although it has a somewhat more blunt tip. The standard MK 14 and MK 15 Torpedo nose is also a calculated profile approximating a 1.2 caliber ogive combined with a slightly tapering section joining the body. All of the other nose designs are standard geometrical shapes as indicated.



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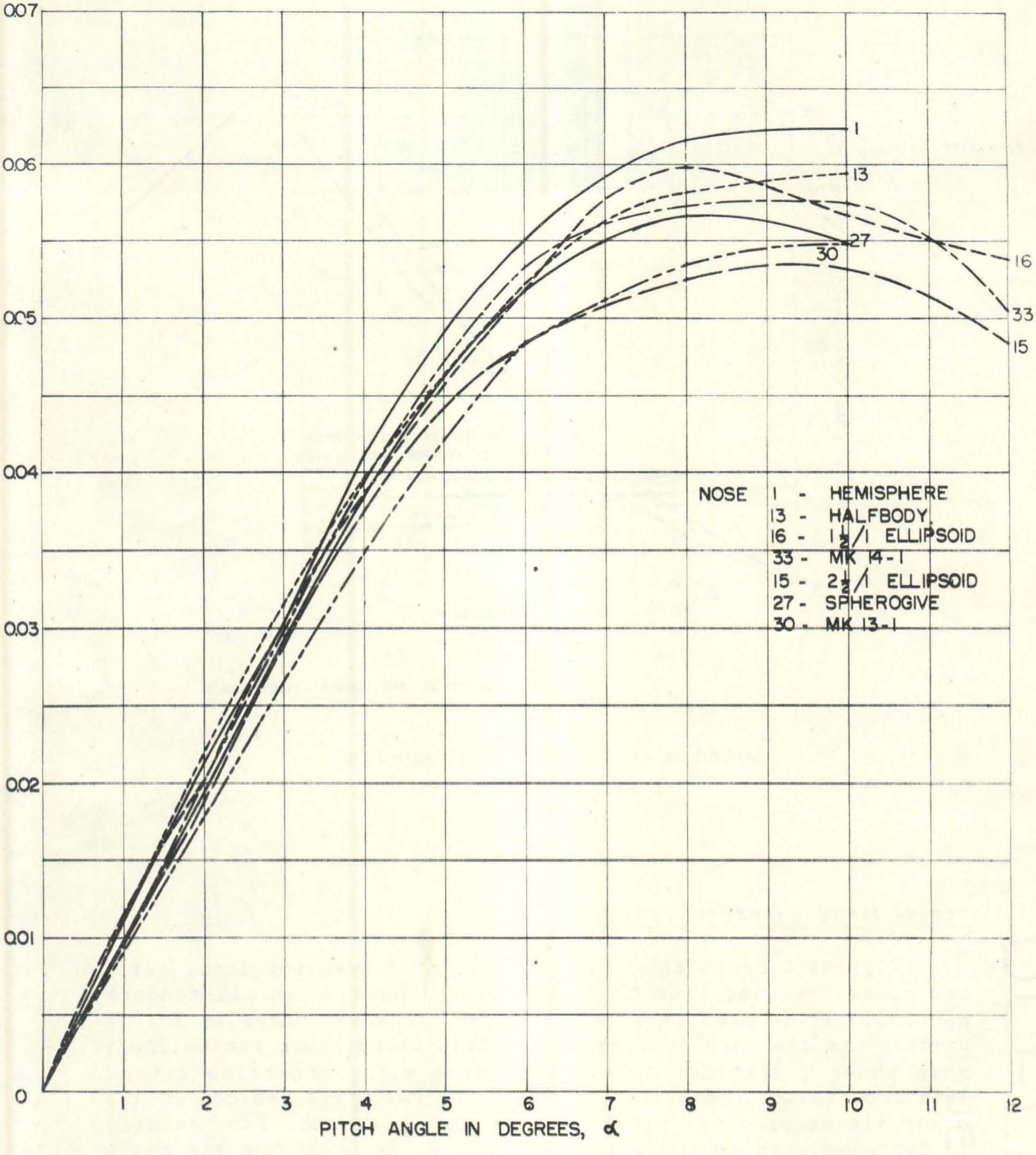
DRAG & LIFT COEFFICIENT CURVES

ALL RUDDERS NEUTRAL

FIGURE 2

PERFORMANCE CHARACTERISTICS

Figures 2 and 3 show the coefficient curves for drag, lift, and moment varying from 0° to 12° pitch angle, with all rudders neutral. It is seen that the lift for the seven noses is fairly uniform and the same is true of the drag except that the halfbody nose shows a distinct decrease in drag with increasing pitch. This amounts to a reduction of about 30% below the average of the other six noses at 8° pitch. It is not reasonable for the drag to decrease with an increasing yaw angle. However, as the cause of this erratic performance has not yet been determined, no more reliable data are available. The moment coefficient curves for the seven noses, all of which show destabilizing moments, also show a gradual divergence reaching a maximum difference at 9° pitch. At this point the hemispherical nose (No. 1) has a moment coefficient 18% greater than that of the 2.5 : 1 ellipsoidal nose (No. 15), with the others falling between these two. The standard MK 13 nose (No. 30A) has a moment coefficient curve agreeing quite closely with that of the 2.5 : 1 ellipsoidal nose.



CORRECTED FOR SHIELD INTERFERENCE

MOMENT COEFFICIENT CURVES

ALL RUDDERS NEUTRAL

FIGURE 3

Figures 4 and 5 show the coefficient curves for drag, lift, and moment varying from -12° to $+12^\circ$ pitch angle, with horizontal rudders set 10° up. It is seen, as with rudders neutral, there is quite close agreement between the various nose designs for the drag and lift. As would be expected, the halfbody nose also shows the lowest drag with this rudder setting.

All of these curves indicate that the seven types of nose have very little effect on the characteristics of the torpedo when it is operating on a steady run.

CONTROL ANGLE

Figure 5 also indicates the control angle* for the various noses with 10° up setting of the horizontal rudders. In all cases there is a destabilizing moment for all positive pitch angles up to $+12^\circ$ (nose up). The amount of this destabilizing moment does not vary greatly for the different nose designs. With negative pitch angles (nose down) there results a stabilizing moment with all noses from 0° to -6° pitch. Between approximately -6° and -12° the hemispherical nose (No. 1) gives a destabilizing moment with a slight similiar effect for the MK 14 and MK 15 nose (No. 33) in the region of -7° to -9° pitch. All of the other noses give a stabilizing moment from 0° to -12° pitch. With 10° up rudder and 0° pitch an average moment coefficient of 0.047 results, which is about equal to 75% of the maximum destabilizing moment coefficient (occurring at $+10^\circ$ pitch) with neutral rudders. (This moment is known as the rudder effect* for 10° rudder).

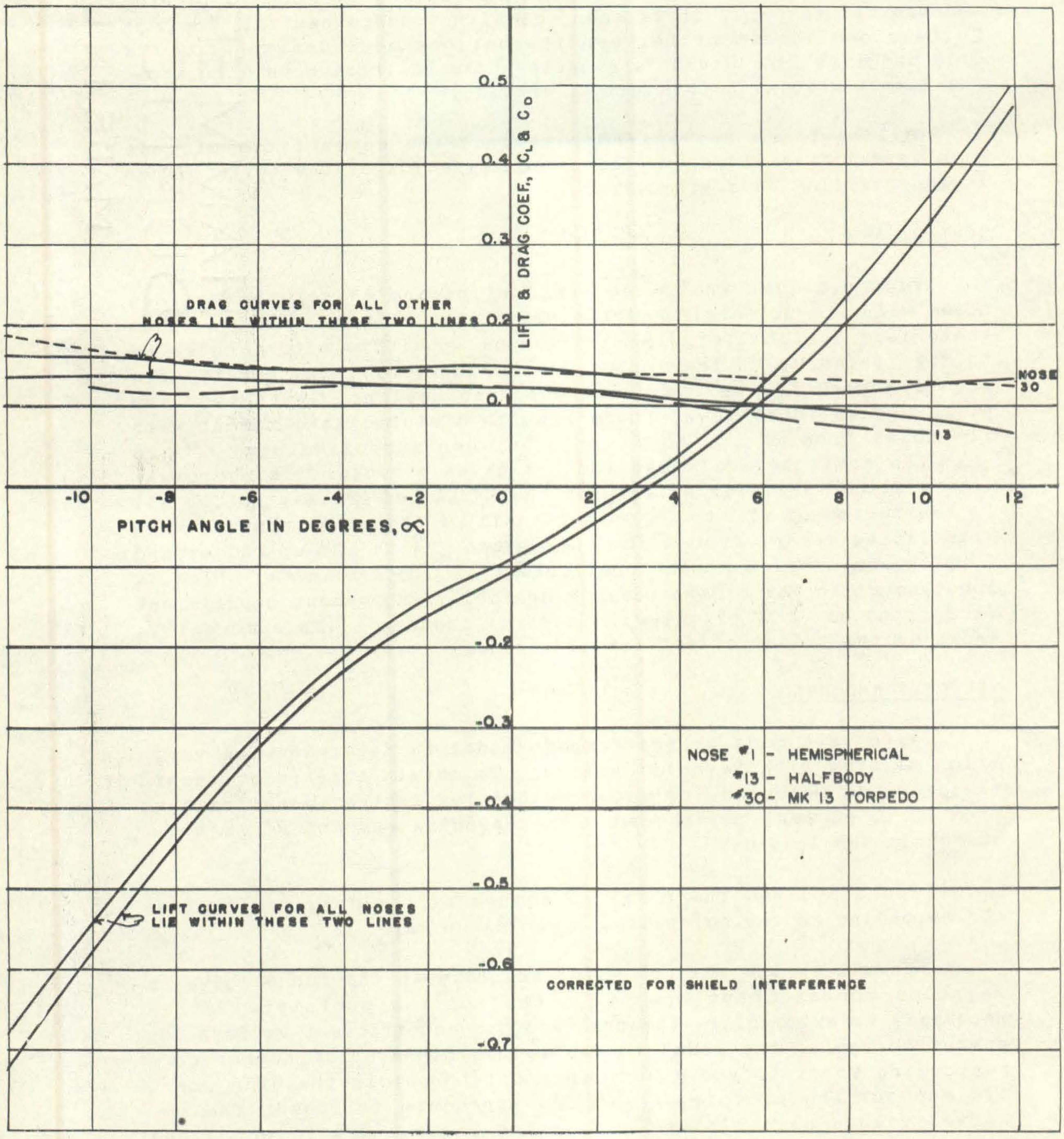
VELOCITY AND DRAG

Tests were made on the torpedo model to determine the variation of drag with Reynolds number. To obtain this relationship the drag was measured for water velocities in the tunnel ranging from 10 to 60 feet per second. The Reynolds number, R, is discussed in the Appendix.

Figure 6 gives the observed values of the drag coefficient corresponding to the calculated Reynolds numbers.

Inasmuch as the maximum water velocity in the tunnel gives a Reynolds number about one-tenth that of the prototype, it is necessary to extrapolate the observed drag coefficient vs Reynolds number curves of the model to the values of Reynolds number corresponding to prototype speed, in order to obtain the drag coefficient for the prototype. In the procedure followed, the observed values were plotted on log-log paper and straight lines drawn to represent as nearly as possible the trend shown by the points. These straight lines were then extended to the prototype Reynolds number as shown in Figure 7. The extended curves, in

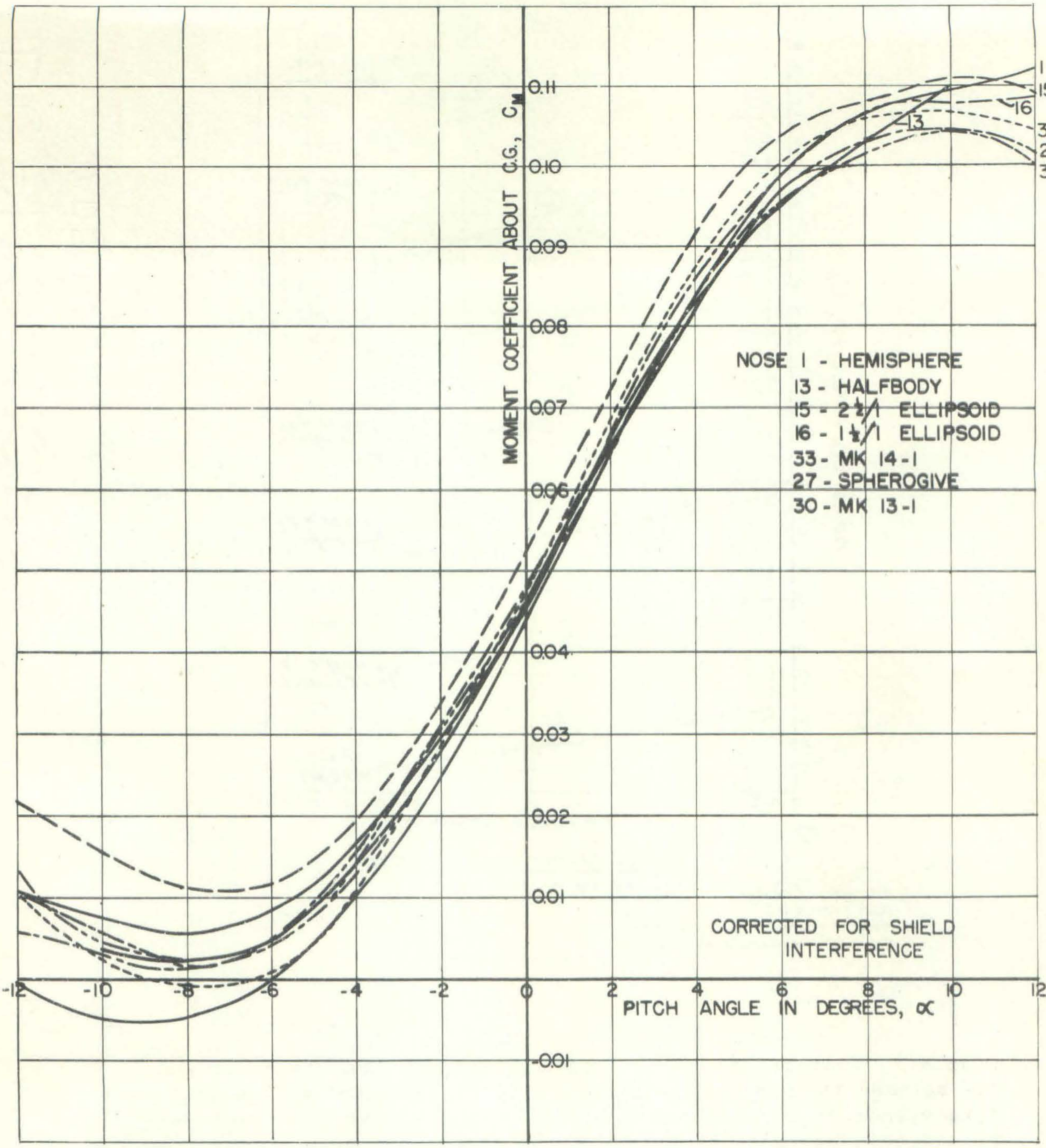
* See Appendix for definition.



DRAG & LIFT COEFFICIENT CURVES

HORIZ. RUDDERS 10° UP

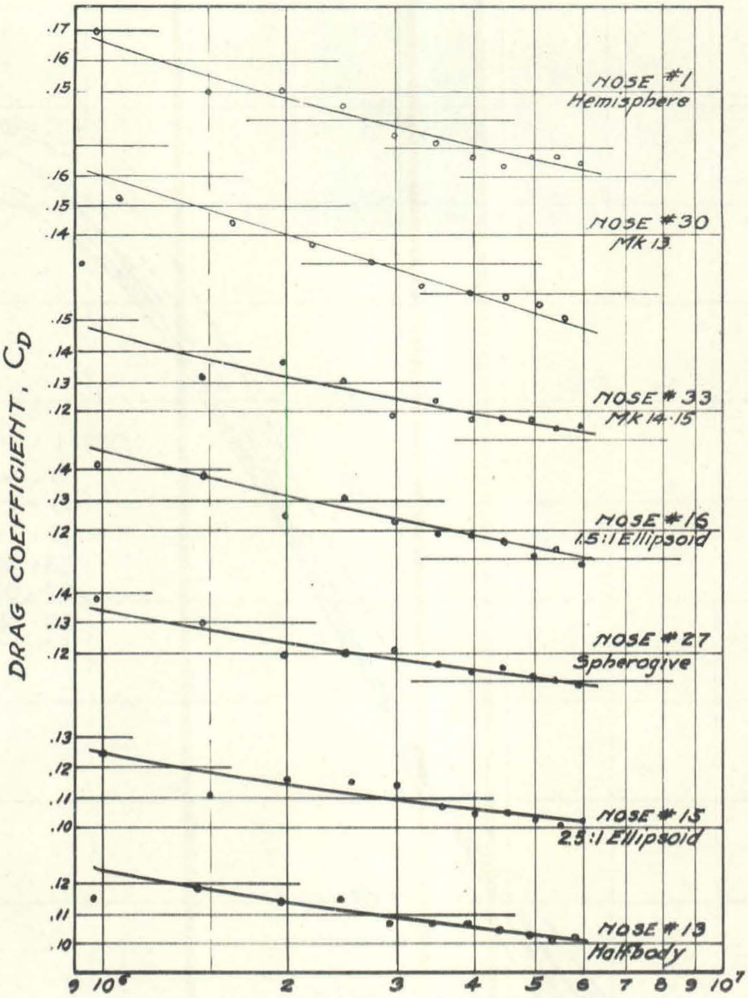
FIGURE 4



MOMENT COEFFICIENT CURVES

HORIZ. RUDDERS 10° UP

FIGURE 5

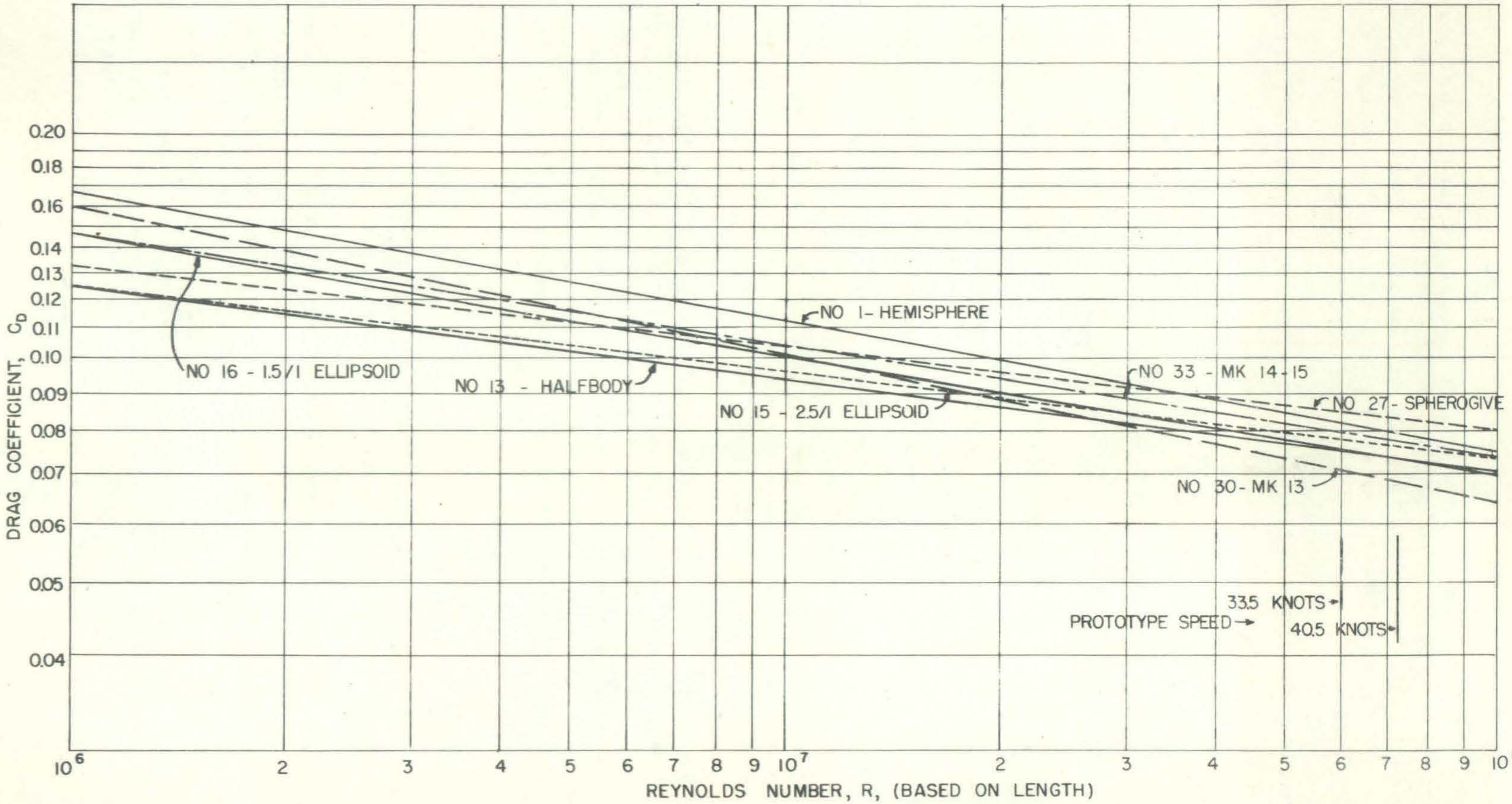


DRAG VS REYNOLDS NUMBER FROM MODEL TESTS

All rudders neutral
Yaw angle = 0
Data corrected for shield interference
Reynolds number based on length.

FIGURE 6

Figure 7, indicate that the drag coefficient for all noses will lie between the approximate limits of 0.07 and 0.085 at the prototype speeds of 33.5 and 40.5 knots. These values show much less spread than do those measured on the models and seem to indicate that effect of the nose on the drag is small. It seems proper to assume from these tests that the drag coefficient for the prototype will be of the order of 0.08 and that it will vary not more than plus or minus 10% for the seven nose designs tested. On the basis of this method of extrapolation, it appears that no material change in drag will result from the use of the different nose types.



DRAG VS. REYNOLDS NUMBER CURVES
EXTRAPOLATED TO PROTOTYPE SPEEDS

FIGURE 7

CAVITATION TESTS

Tests were made to determine the point of incipient cavitation for the various noses and also the variation in the cavitation parameter (K) with changes in yaw angle. Photographs were taken to show the cavitation effects at various values of K for all noses.

The values of the cavitation parameter, K*, for incipient cavitation are as follows:

Nose No. 1	Hemisphere	K = 0.75
Nose No. 30A	MK 13 Spherical Tip	K = 0.67
Nose No. 33	MK 14 and MK 15 Torpedo	K = 0.43
Nose No. 13	Halfbody	K = 0.39
Nose No. 27	2.0 caliber x 65 1/2° spherogive	K = 0.39
Nose No. 16	1.5 : 1 Ellipsoid	K = 0.54
Nose No. 15	2.5 : 1 Ellipsoid	K = 0.31

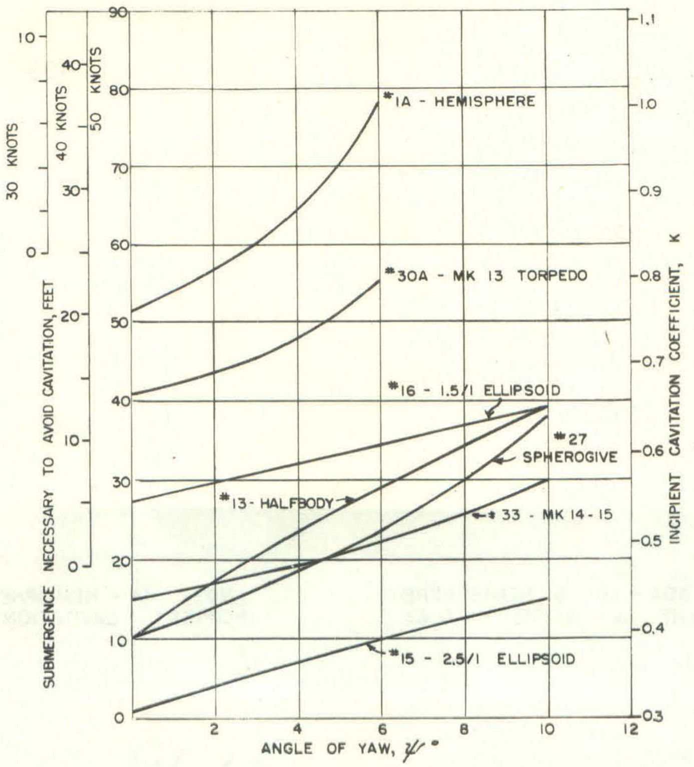
Some of the values of K shown above may differ slightly from those included in previous reports due to more exact laboratory technique, more accurate models, etc.

Figures 9 and 10 show photographs of the model, in the tunnel, fitted with the various noses under conditions of velocity and pressure representing values of K from 0.71 to 0.21. It is evident from these photographs that there is a wide variation in the cavitation effect produced by the different noses for the same values of K, or, in other words, for the same velocity and submergence.

CAVITATION AND YAW

The angle of yaw, or pitch, of a projectile has a decided effect on the value of K at which incipient cavitation is observed. Careful observations of the beginning of cavitation were made for yaw angles from 0° to 10°. These results are plotted in Figure 8 and it is seen that a 10° yaw angle will increase the value of K between 22% and 70%, depending on the type of nose. The halfbody nose (No. 13) shows the greatest percentage of increase in K with increase in yaw, and the 1.5 : 1 ellipsoidal nose (No. 16) shows the least. This increase in the value of K with increasing yaw angle means that if, at a given velocity and submergence, the projectile comes very close to cavitating at zero yaw, there must be a decided increase in submergence with yaw if cavitation is to be avoided.

* See Appendix for definition of K



RELATION BETWEEN SUBMERGENCE,
YAW, SPEED, AND K

FIGURE 8

In Figure 8 are included scales showing the submergence required to avoid cavitation at various yaw angles and speeds. This chart shows that at a speed of 40 knots, several of the noses will not cavitate at zero submergence if the yaw angles do not exceed those shown below:

Nose No. 15 (2.5 : 1 Ellipsoid)	10°+
Nose No. 33 (MK 14 and MK 15 Torpedo)	4°
Nose No. 27 (2.0 caliber x 65-1/2° Spherogive)	4°
Nose No. 13 (Halfbody)	2.5°

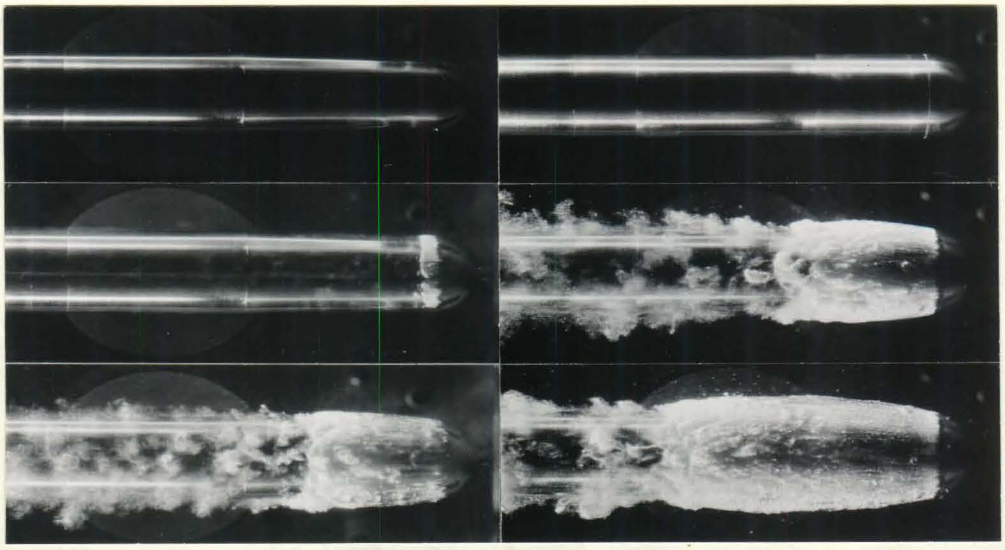
For the other noses the submergence required to avoid cavitation at 40 knots and <u>zero</u> yaw is as follows:

Nose No. 16 (1.5 : 1 Ellipsoid)	5 feet
Nose No. 1 (Hemisphere)	20 feet
Nose No. 30A (MK 13 Spherical Tip)	13 feet

(a) K = 0.62

(b) K = 0.54

(c) K = 0.31



(d) K = 0.71

(e) K = 0.35

(f) K = 0.27

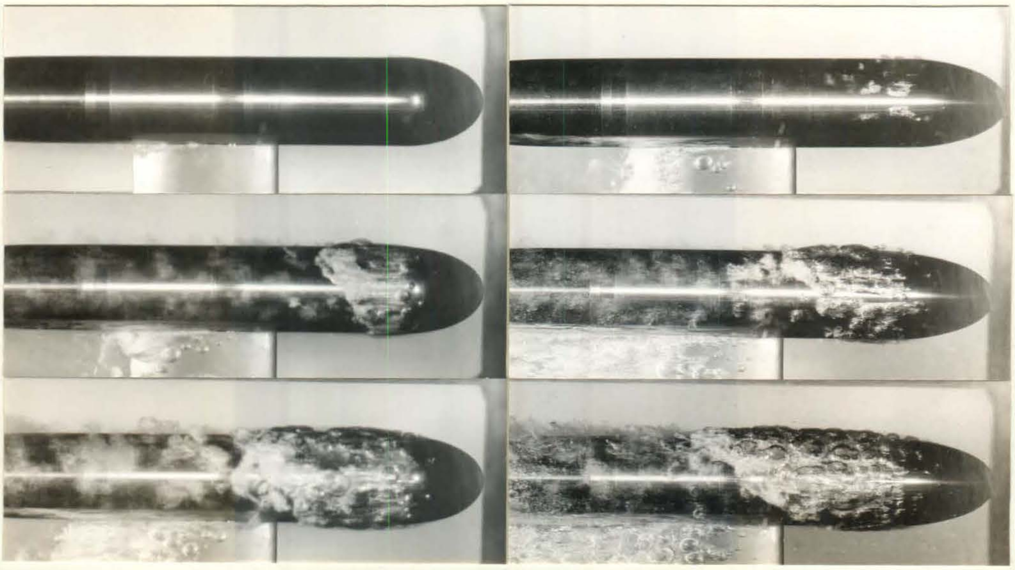
NOSE 30A - MK 13 HEMISPHERE
INCIPIENT CAVITATION K = 0.67

NOSE 1A - HEMISPHERE
INCIPIENT CAVITATION K = 0.75

(g) K = 0.42

(h) K = 0.33

(i) K = 0.27



(j) K = 0.32

(k) K = 0.26

(l) K = 0.21

NOSE 16 - 1.5:1 ELLIPSOID
INCIPIENT CAVITATION K = 0.54

NOSE 33 - MK 14-15 STANDARD
INCIPIENT CAVITATION K = 0.43

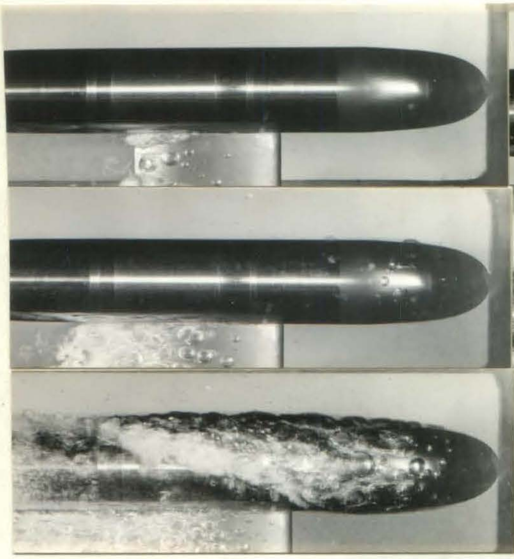
CAVITATION PHOTOGRAPHS

FIGURE 9

(a)
K = 0.33

(b)
K = 0.27

(c)
K = 0.21

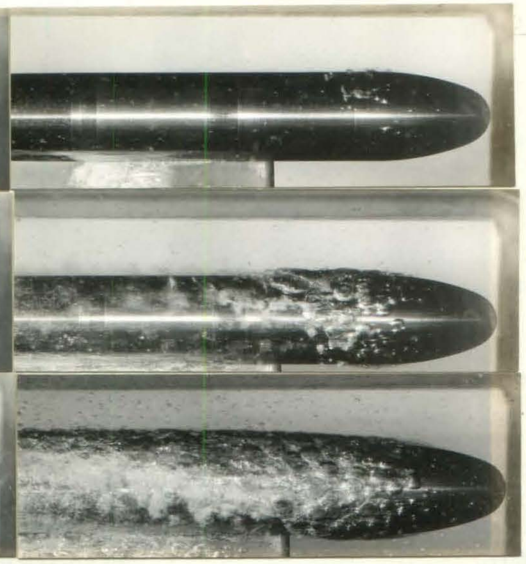


NOSE 13 - HALFBODY
INCIPIENT CAVITATION K = 0.39

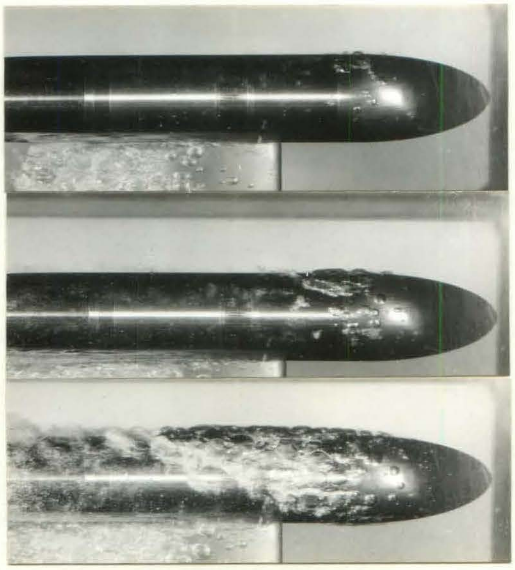
(d)
K = 0.31

(e)
K = 0.26

(f)
K = 0.22



NOSE 27 - 2.0 X 65$\frac{1}{2}$° SPHEROGIVE
INCIPIENT CAVITATION K = 0.39



(g)
K = 0.26

(h)
K = 0.25

(i)
K = 0.21

NOSE 15 - 2.5:1 ELLIPSOID
INCIPIENT CAVITATION K = 0.31

CAVITATION PHOTOGRAPHS

FIGURE 10

CONCLUSIONS

With neutral rudders and for pitch angles up to 10°, the lift coefficient, for a given nose, does not vary more than plus or minus 5% from the average of the seven noses tested.

The hemispherical nose (No. 1) has the highest destabilizing moment coefficient with neutral rudders, and the 2.5 : 1 ellipsoid (No. 15) the lowest, being about 15% lower than No. 1 for a wide range of pitch angles.

With the horizontal rudders set 10° up, the seven noses have practically the same lift coefficient.

Setting the horizontal rudders 10° up results in a stabilizing moment coefficient with all noses up to -12° pitch angle with the exception of the hemispherical nose, which becomes unstable for pitch angles between -6° and -12°. At -8° pitch the stabilizing moment coefficient for all noses, excepting the hemispherical, varies between zero and approximately 0.01.

Drag coefficients for the prototype determined by extrapolation of the model results to prototype speed, indicate that the drag is about the same for all of the seven nose shapes. These results indicate that the drag coefficient for the prototype at 33.5 and 40.5 knots will be of the order of 0.08 with the values for all noses falling within plus or minus 10% of that value.

The greatest variation in the performance of the seven noses is in regard to the submergence required to avoid cavitation. At zero yaw and 40 knots speed, the MK 13 (No. 30A) and hemispherical (No. 1) noses require about 13 feet and 20 feet submergence, respectively, to avoid cavitation; the 1.5 : 1 ellipsoid (No. 16) requires 5 feet; and all of the others will not cavitate at this speed even with zero submergence. There is a decided increase in submergence required to avoid cavitation with increasing yaw angles. To avoid cavitation at a speed of 40 knots the submergence at 6° yaw must be increased over that at zero yaw as follows: 85% for the hemispherical nose (No. 1), 70% for the MK 13 nose (No. 30A), and 80% for the 1.5 : 1 ellipsoidal nose (No. 16). At a speed of 40 knots the 2.5 : 1 ellipsoid (No. 15) will not cavitate at zero submergence with yaw angles somewhat over 10°. At zero submergence and 40 knots speed there will be no cavitation until the yaw exceeds the following values for the other noses: MK 14 and MK 15 (No. 33) 4°, spherogive (No. 27) 4°, and halfbody (No. 13) 2.5°.

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (-).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (-) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (-) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (-). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (-).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or the opposite sign of the pitch angle.

In all model tests the moment is measured about the point of support. Moments about the center of gravity of the projectile have the symbol, M_{cg}.

NORMAL COMPONENT, N

The sum of the components of the drag and cross force acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \qquad (1)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \qquad (2)$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \quad (3)$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \quad (4)$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \quad (5)$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D= Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

CONTROL ANGLE

In considering the effect of rudders on static stability, either in yaw or pitch, the term "control angle" is used to denote the yaw below which a given rudder setting with opposite sign to the yaw will tend to return the projectile to zero yaw, and above which the yaw will further increase. The control angle is useful for indicating the effectiveness of rudders and for comparing the static stability of different projectiles with equal rudder settings.

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \qquad (6)$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}} \qquad (7)$$

in which

K = Cavitation parameter

P_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

P_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \qquad (8)$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing applitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability or instability can be obtained from the center-of-pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.

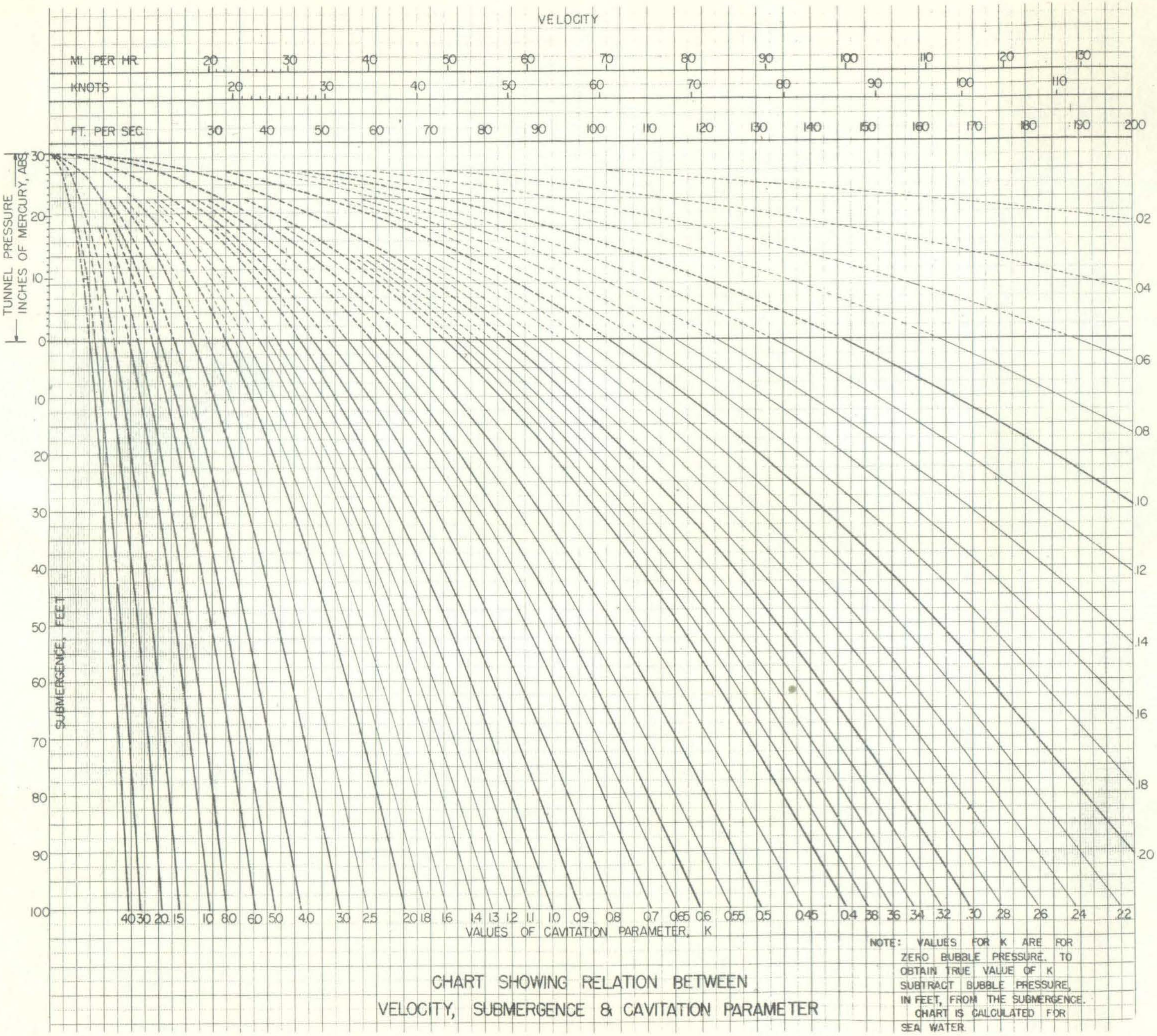


CHART SHOWING RELATION BETWEEN VELOCITY, SUBMERGENCE & CAVITATION PARAMETER